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Date deposited: 10th February 2011

Version of file: Author final

Peer Review Status: Peer reviewed

Citation for item:

Marinov M, Mortimer P, Zunder T, Islam D. [A Steady State Analysis for Yard Performances](#). *RELIT - Revista de Literatura dos Transportes* 2011, **5**(1), 33-49.

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Diretório de Pesquisas**Análise *Steady-State* do Desempenho das Gares de Triagem**Marin Marinov 1[†]Philip Mortimer 2[‡]Tom Zunder 3[§]

Dewan MZ Islam ١١

Resumo

As gares de triagem têm um papel vital na prestação dos serviços de transporte de carga ferroviária. Estas instalações funcionam como centros de junção e redistribuição das mercadorias na rede ferroviária e possuem importantes recursos fixos e móveis. Na perspectiva dos clientes do serviço de carga, as gares de triagem não acrescentam grande valor no produto final. Mesmo para os operadores ferroviários, as gares de triagem são muitas vezes encaradas como elementos causadores de atrasos e introduzem perdas para o negócio. Daí que, para ambos, uma operação ineficiente das gares de triagem não é um factor desejável. Neste artigo, são estudadas gares de triagem de “dupla entrada e sem declive” através da teoria de filas de espera, usando G/G/m. Os resultados obtidos demonstram baixos

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níveis de utilização das várias partes que constituem as gares de triagem estudadas. Face a análise efectuada são propostas medidas para a melhoria da eficiência das gares de triagem através de mudanças nas regras de circulação e são discutidos esquemas de produção para as mesmas.

Palavras-chave: Carga ferroviária 1, Gares de triagem 2, Filas de espera 3, G/G/m 4, Esquemas de produção 5.

Research Directory**A Steady State Analysis for Yard Performances**Marin Marinov 1^{**}Philip Mortimer 2^{††}Tom Zunder 3^{‡‡}Dewan MZ Islam^{¬¬}**Abstract**

Yards play an important role for the quality of rail freight services. These facilities function as reassembly hubs in rail freight networks and incorporate a significant amount of static and dynamic resources. From the customer's perspective yards are thought of as an element that adds a little value to the final product. From the rail operator's perspective yards are seen as a main source of delay and loss of business. Therefore, running yards inefficiently is not acceptable. In this paper, a double-ended flat-shunted yard has been studied by G/G/m queues. The results obtained demonstrate significantly low utilisation levels of the yard subsystems in question. Therefore, possible improvements through changes in traffic rules and production schemes are discussed.

Key words: Rail freight 1; Shunting yards 2; Freight trains 3; G/G/m queues 4; Production schemes 5.

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1. Introduction

Rail freight yards play a very important role in the traditional (orthodox) rail freight service. These facilities function as reassembly hubs in rail freight networks, reassembling freight wagons into freight trains. Yards also serve as storage points where freight wagons currently not in use are stored while awaiting their next assignments.

Rail freight yards are a major component of the rail freight industry's commercial and economic infrastructure. They are designed to facilitate the mixing and sorting of freight flows between multiple traffic origins and destinations to arrange freight movements in as cost effective way as possible. Yards are a major cost to rail operators and the most efficient and effective use of the resources they represent needs to be the overarching focus of the railway administration managing and operating them. They allow freight flows from diverse sources to be combined into train formations for onward movement again with the aspiration of being as cost-effective as possible.

In contrast, yards are viewed as a mechanism that blocks and delays the movement of trains and in some cases this has been a problem with wagons and cars lost for long periods that has had an unfortunate impact on rail's reliability, punctuality and competitiveness. The dwell time in terminals needs to be minimised to ensure competitive transit times with competing intra- and inter-modal operators.

The use of yards to assemble and break down trains has been threatened by a number of developments including the adoption of point to point services that are deemed to be cost effective in terms of load such as to remove the requirement for any intermediate marshalling or reconfiguration of the train once assembled at the start-point. This development has featured in the inter-modal sector where intermediate marshalling has been ruled out in order to minimise train delays and also to bulk hauls moving directly from production points (mines/quarries/refineries) to delivery points for consumption or onward local distribution by road. The use of pre-blocked wagon and car formations within a longer train formation allowing sections to be released to sidings and spurs with the corresponding collection of sections is another means of avoiding the use of large main marshalling yards. The original train assembly may be in a large classification area but subsequent train configuration adjustments are made in transit using the head-end traction for switching and shunting.

The block train concept does, however, have limitations that may preclude its use. Where mixed formations of commodities can be assembled into train formations that are cost effective then the use of marshalling yards to underpin this activity can be justified. This could apply equally to long and short haul flows on a scheduled or on-demand basis. Where traffic is aggregated from the accumulation or dispersed in the form of small flows for trip workings to points of origin or destination then again yards have a credible and valid role. The cost of this type of operation does, therefore, need to be minimised or the economic advantages of rail for medium and long haul traffic are eroded.

Yard functions can and have been modernised and made more efficient by a wide array of technical and operational measures to minimise manpower and allow train configurations to be planned and managed in order to maximise throughput. Wagon and railcar dwell times can and need to be minimised as a consequence of these initiatives. To ensure maximum yard productivity implies a 24/7 availability. Marshalling trains with a minimal manual impact is a key commercial and operational objective. There are obvious safety issues in yards being worked at night and in poor weather conditions. The interaction and relative precedence of commercial imperatives in relation to the actualities of yard working conditions is an integral component of their routine operation.

A major technical issue with rail yards is the need to remove main line traction on arrival (and by implication restore main line traction resources when a new train formation or consist is completed and ready to move). The manipulation of wagons or freight cars requires flexible and powerful traction to manipulate and sort train formations. The vast majority of marshalling yards use diesel shunters or switch engines for this as the most cost effective method. Some railways use electric traction for shunting duties within yards and this implies a significant capital outlay if this option is selected. Here, the benefits of reduced noise and emissions may be of increasing importance.

Individual railroad administrations will elect to use marshalling yards or other options including block trains depending upon their relative efficiency and competitiveness. If yards are retained it is of the utmost importance that they are cost effective and do not constrain rails service and cost competitiveness. The increasing speed and efficiency of the primary

competing mode and the ability to offer door to door transits is something that the rail freight operators need to recognise more fully and to accept that this sort of voracious competition has taken significant volumes of traffic from rail because of deficiencies in product and service offers (including yard dwell times). For yards to remain an integral part of the railway service offer they need to be as efficient as possible with minimum dwell times for vehicles being handled. Yard costs as a component of total journey need to be kept under continuing scrutiny and so minimised.

Yards play a very important role for the rail freight service quality. These facilities are thought of as a main source of delay and loss of business. They are also thought of as a non-revenue element in providing the service, meaning an element that basically generates only costs for the rail operator without adding a significant value to the final product. Therefore, running yards inefficiently is not acceptable.

To increase the level of yard efficiency and productivity analytical models and simulations have been used. It is our contention that the interest of studying yard behaviour by analytical methods has faded. Therefore, this paper is also an invitation to revive the interest in this topic. We analyse and evaluate double-ended flat-shunted yard performances using G/G/m queues. These queues make it possible to directly analyse queuing processes without employing simulation. The concept is restricted though and applies to a limited class of queuing systems that are said to operate in steady state.

Petersen (1977 a, b) is one of the pioneers in analysing and modelling the yard operations as queuing phenomena using queuing systems. This idea is taken further by Martland (1982), Turnquist and Daskin (1982), Tasev and Karagyozev (1983), Karagyozev et al. (1990a, b) Katchaunov et al. (1998). The moving spirit behind is to explore yard behaviour as related to physical configuration and production schemes. M/M/m, M/M/m/, M/D/m, M/E_k/m, M/G/m (where, $m = 1, 2, \dots, n$), etc. are used. The main objective is to estimate the average throughput time of the yard under study.

In general, queuing systems provide quick insights into the system under study. These methods do not require a significant amount of data to be collected and processed. Instead, the steady state predictions are based on parameter estimates from a limited set of observations.

Steady-state analysis has another advantage: it highlights important relationships between the queue's performance and the queue's characteristics. These relationships are nearly impossible to identify from simulation. Despite these comments, simulation does not lack appeal, for it is a much more robust technique, capable of dealing with virtually any probability distribution. Hence, with simulation, one is less likely to compromise the accuracy of the model structure, as in adopting the exponential service time distribution when it is not correct (Hall 1991).

The paper includes a study of yard performances modelled by G/G/m queues and is organized, as follows: Section 2 provides a discussion on analytical queuing models for analysing yard performances. We model yard performances using G/G/m queues. Section 3 implements G/G/m models to study double-ended flat-shunted yard performances and discusses the obtained results. The current level of performances is investigated and scenarios for improvements are suggested. We wrap up with conclusions in Section 4.

2. Yard Performances Modelled by G/G/m Queues

For the purposes of this discussion shunting yard performances are modelled by G/G/m queues. We model using G/G/m because it is least susceptible to random fluctuations, and it could be considered equivalent to running the simulation for an infinite length of time (Hall 1991). Based on the decomposition approach (Dessouky and Leachman 1995, Marinov and Viegas 2009b), the modeller divides the yard under study in yard areas/subsystems (Pachl 2002). For our purposes four clearly defined yard areas (subsystems) are identified, as follows:

- 1) Arrival Yard;
- 2) Shunting Zone;
- 3) Locomotive Depot;
- 4) Departure Yard.

The concept adopted in analysing yard performances is to follow the throughput line of the yard under study. Figure 1 shows this graphically and reads, as follows:

- 1) a number of inbound freight trains arrive in Arrival Yard - $\lambda_{G1,in}$;
- 2) the inbound freight trains are accommodated on the tracks of Arrival Yard (i.e., $G1$), where they may queue in $Q1_{,G1}$ and $Q2_{,G1}$ before to be processed by the arrival yard personnel indicated with $S1_{,G1}$ and $S2_{,G1}$;
- 3) once a freight train is served in Arrival Yard, its road locomotive is sent to Locomotive Depot (i.e., $G3$) and the train composition is ready for reassembling. The reassembling is fulfilled in Shunting Zone (i.e., $G2$), where the train composition may queue in either $Q1_{,G2}$ or $Q2_{,G2}$ before to be processed by the shunting brigades indicated with $S1_{,G2}$ and $S2_{,G2}$;

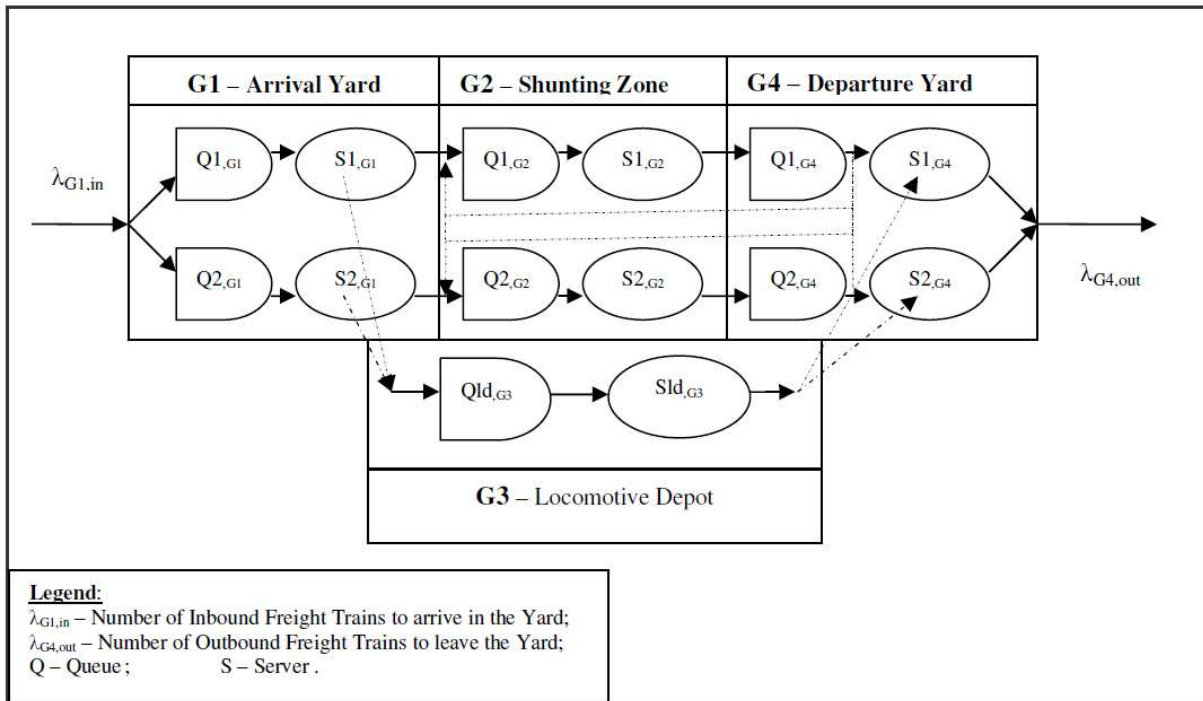


Figure 1 Throughput Line of the Yard under Study

- 4) the service in Shunting Zone is completed when an outbound freight train composition is made up and moved to Departure Yard (i.e., $G4$). There the outbound freight train compositions may queue in $Q1_{G4}$ and $Q2_{G4}$ before to be processed by the departure yard personnel indicated with $S1_{G4}$ and $S2_{G4}$. The service in Departure Yard includes: arriving and putting road locomotive(s) on assembled train compositions, full brake tests of the outbound freight train as well as operations on outbound freight train departure.
- 5) when all the service in Departure Yard is completed the outbound freight trains leave the yard - $\lambda_{G4,out}$

It should be noted that the formulae for G/G/m queues (for either $m = 1$ or $m = 2$) are not exact and that is why for our purposes the approximations provided by *Allen and Cunneen* are used (consult e.g. Hall 1991, p. 153). More specifically, by Allen and Cunneen formulae we are able to compute the expected freight trains in queue per yard subsystem ($L_{q,Gi}$) and then the other measures of yard performances (such as: Freight trains in Gi-yard subsystem ($L_{s,Gi}$), Time in the Queue of Gi-yard subsystem ($W_{q,Gi}$) as well as Time in Gi-yard subsystem ($W_{s,Gi}$)) are easily obtained by Little's formulae (Little 1961).

An important measure that we are able to obtain analytically is the utilisation rate of a single server. For instance we are able to compute the utilisation rates of the yard crews for a certain period of time (per unit time). Based on Queuing theory, for a single server at the Gi-yard subsystem, say $\rho_{Gi}(Server)$, such measure can be computed using the following formula:

$$\rho_{Gi}(Server) = \frac{\lambda_{Gi}}{\mu_{Gi} * S(m)_{Gi}} \rightarrow m = 2 \quad (1)$$

where,

λ_{Gi} – number of freight trains that require service at Gi-yard subsystem per unit time;

μ_{Gi} – number of freight trains served by Gi-yard subsystem per unit time;

$S(m)_{Gi}$ – number of server employed at Gi- yard subsystem.

Furthermore, if we know the number of freight trains that require service at Gi-yard subsystem per unit time (λ_{Gi}) as well as the average dwell time per freight train in Gi-yard subsystem we are then able to estimate the minimum number of tracks required in this Gi-yard subsystem, say $M_{tracks(?),Gi}$ by satisfying the following condition:

$$\frac{\lambda_{Gi} * W_{s,Gi}}{M_{tracks(?),Gi}} < 1 \quad (2)$$

By applying analytical queuing models employing G/G/m queues for studying yard performances, one obtains a set of measures, discussion of which is presented in the next section of this paper where we discuss a real-world case.

While the analytical queuing models provide a quick insight into the performance of the yard being examined without requiring detailed data, they have significant shortcomings. These models are disabled to provide a detailed replication of the dynamic yard behaviour and therefore, they should be used as a preliminary study in analysing and evaluating yard performances followed, for instance, by event-based simulations (Marinov and Viegas 2009a).

An itemized description of analytical queuing models employing G/G/m queues in modelling yard performances is provided elsewhere and we shall not repeat it here. The interested reader is advised to consult Marinov 2007, Marinov and Viegas 2009a. Instead, in the next section, we apply G/G/m queues for studying double-ended flat shunted yard performances and discuss the results obtained.

3. Case Study: Double-Ended Flat-Shunted Yard Performances Studied by G/G/m Queues

G/G/m queues have been used in studying the level of productivity of the Double-Ended Flat-Shunted Yard “Entroncamento”. Entroncamento is the biggest facility of this type in Portugal. This facility is equipped with 28 tracks, 23 of which are operational. Track No 24 is a non-electrified lead leading to a wagon workshop. The electrified yard tracks are 15 - 22. Track No 23 is planned to be electrified. Tracks 1 to 10 are mainly used as storage area for empty and damaged wagons. A specific feature is that:

- the classification work within Entroncamento is fulfilled by two employees;
- the shunting work is performed by two shunting crews, meaning there are two shunting locomotives in operation at any time;
- the inspection work after freight train arrivals and before freight train departures is executed by two employees as well.
- none of the pairs of working resources work simultaneously on the same freight train.

Table 1 A Comparison between Observed and Estimated Means

Time in Yard Areas		
Subsystems	Observed Means	Estimated Means
<i>Arrival Yard (WsG1)</i>	20 min/train	20.74 min/train
<i>Shunting Zone (WsG2)</i>	30 min/train	30.41 min/train
<i>Waiting for Road Locomotive (WsG3)</i>	20 min/train	20 min/train
<i>Departure Yard (WsG4)</i>	25 min/train	25.77 min/train

Recalling G/G/m queues, the calibration of the analytical queueing model is presented in Table 1. We observe a good comparison between the observed means and the estimated means of the throughput times per specified yard areas i.e., Arrival Yard (WG1), Shunting Zone (WsG2), Waiting for Road Locomotive (WsG3) and Departure Yard (WsG4). It should be noted that, for yard analytical modelling purposes, the average time for waiting a road locomotive is assumed as given. Its value is obtained through observations and timing, and is explicitly considered as waiting time of already assembled train compositions.

Next, the characteristics of the current situation and the necessary inputs for analytical queuing modelling, together with some of the estimated measures of Entroncamento subsystems' performances are given in Table 2. Note that according to the current situation there are 28 regular inbound freight trains to be served by Entroncamento yard for 24 hours. The regular outbound freight trains, however, come up to 29, meaning in the shunting zone 28 freight trains are broken down and 29 freight trains are made up. Therefore, because of this phenomenon the arrival rate from Shunting Zone to the next areas is increased.

Table 2 Current Situation, Inputs and Outputs

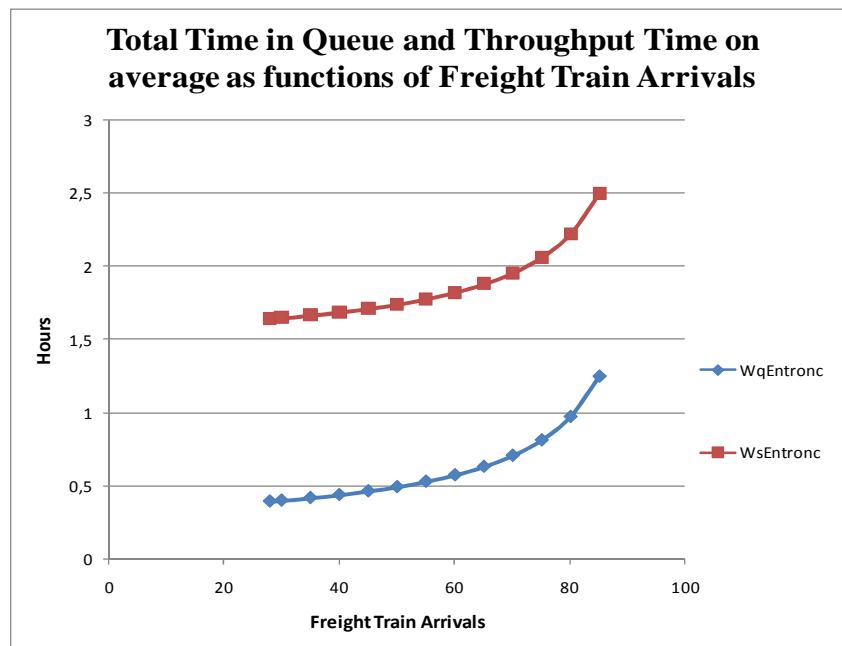
G/G/m queues – Inputs and Outputs				
Definitions	Arrival Yard	Shunting Zone	Waiting for Road Locomotive	Departure Yard
<i>Arrivals-Gi</i>	28 trains/24	28 trains/24	29 trains/24	29 trains/24
λ_{Gi}	1.167	1.167	1.208	1.208
<i>Service Time-Gi</i>	20 min	29.71 min	-	25.26 min
μ_{Gi}	3	2.019	-	2.375
$S(m)_{Gi}$	2	2	-	2
$\rho_{Gi}(\text{Server})$	0.194	0.289	-	0.25
$L_{q,Gi}$	0.014 number	0.045 number	-	0.01 number
$L_{s,Gi}$	0.4 number	0.623 number	0.39 number	0.52 number
$W_{q,Gi}$	0.012 hours/train	0.039 hours/train	-	0.008 hours/train
$W_{s,Gi}$	0.35 hours/train	0.53 hours/train	0.33 hours/train	0.429 hours/train

The results given in Table 2 show that the utilization level of Entroncamento yard subsystems (i.e., $\rho_{Gi}(\text{Server})$) is relatively low; less than 30%. A low level of servers' utilization means a significant percentage of resources are idle, and hence the capital costs of the rail company are on the increase.

One of the reasons for such a situation could be that the yard is not fed enough traffic and therefore its subsystems experience such low levels of utilization. Thus, one possible way to increase the utilization levels is to increase in the arrival rate, meaning the number of freight trains to be served by the yard. However, due to limited yard capacity, fluctuations and other external factors, increases in the arrival rate could cause undesirable increases in Time in queue and hence the throughput time per freight train on average will be on the increase too.

Figure 2 shows Total Time in Queue, indicated with “ W_q Entronc”, and Throughput Time in Entroncamento yard per freight train on average, indicated with “ W_s Entronc”, as functions of freight train arrivals. Note that if there were 85 freight trains to be served by Entroncamento yard, then the average throughput time per freight train is estimated to approximately 150 minutes, which is an awkward situation. Therefore, in dealing with yard production levels, it is suggested that one specifies an upper bound to reliably replicate the processing capability of the yard in question. Relying upon Figure 2, we would suggest that this upper bound is between 65 - 70 freight trains per 24 hours in the context of Entroncamento double-ended flat-shunted yard.

Figure 2 Increases in Freight Train Arrivals vs. Total Time in Queue and Average Throughput Time



Generally speaking, ameliorating yard performances is not an easy task. Ameliorations of yard performances could be experienced by adding a new server. It could be a new yard crew or a new shunting engine. However, such a decision should be very well thought of. If there are no changes in the production scheme, adding a new server is expected to reduce Total

time in queue per freight train on average, however it may not decrease significantly Service time of freight trains. Yards are facilities characterising with limited capacity. If there is no infrastructure for two shunting engines to operate simultaneously at any time, adding another shunting engine will not lead to a breakthrough, just on the contrary, more conflicts within the yard limits will be created. Consequently, in searching for improvements one should first analyse the production scheme of the yard in question. Changes in the service processes could increase the rate at which the freight trains are processed and hence lead to reductions in service times. A reduction of service times decreases the throughput time per freight train on average and further creates operating capacity.

Recalling Entroncamento yard, let us be reminded that this flat-shunted yard is classified as a double-ended yard because there are pairs of working resources that operate separately from each other at one end of the yard only, meaning one shunting crew operates at the left end of the yard, another shunting crew operates at the right end of the yard, one classification employee serves the freight trains assigned North, another classification employee serves the freight trains assigned South, and so on. The pairs of working resources can work simultaneously on the same train regardless of the assignment of this train because the layout of Entroncamento yard allows it. That is where amelioration could be found. If the pairs of working resources serve the same freight train simultaneously, a reduction of service times will be experienced. If the two shunting crews break down the same freight train composition at the same time, this process will be fulfilled faster than if there is only one shunting crew in operation; if the two classification employees work simultaneously on the same freight trains, the classification process will be executed faster than if it is only one classification man in operation and so on.

Figure 3 compares Average Throughput Times estimated for “One Crew working on One Freight Train” and “Two Crews working on the Same Freight Train”. It appears that if the yard applies the scenario of “Two Crews working on the Same Freight Train”, than the facility would experience a reduction of approximately 25 minutes in the average throughput time per freight train.

Figure 3 Comparison of Average Throughput Times estimated for “One Crew working on One Freight Train” and for “Two Crews working on the Same Freight Train”

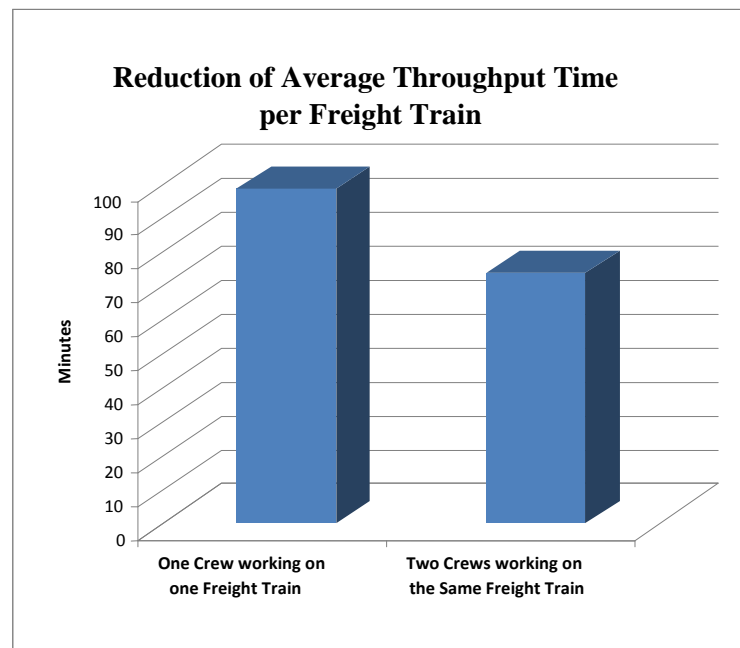
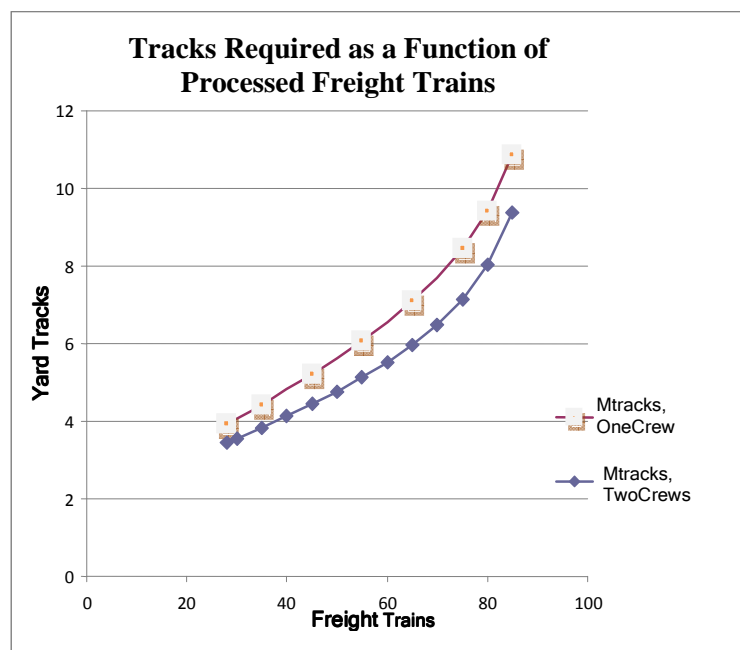


Figure 4 Number of Yard Tracks required for “One Crew working on One Freight Train ($M_{tracks, OneCrew}$)” and for “Two Crews working on the Same Freight Train ($M_{tracks, TwoCrews}$)”



“Two Crews working on the Same Freight Train” will require fewer tracks than “One Crew working on One Freight Train” to fulfil the same amount of work. The absolute minimum number of yard tracks required for the fulfilment of operating processes with freight trains at the yard is computed by multiplying the throughput flow in number of freight trains by the average throughput time estimated per freight train plus two additional tracks to ensure the standing capacity for seamless operations is sufficient. Figure 4 shows the curves obtained for the minimum number of yard tracks required for both “One Crew working on One Freight Train” indicated with $M_{tracks,OneCrew}$ and “Two Crews working on the Same Freight Train” indicated with $M_{tracks,TwoCrews}$. The difference between $M_{tracks,OneCrew}$ and $M_{tracks,TwoCrews}$ is apparent.

4. Conclusions

In this paper double-ended flat-shunted yard performances are analysed and evaluated using G/G/m queues. It is our contention that the interest of studying yard behaviour by analytical methods has fed. Analytical queues, such as G/G/m queues, analyse queuing processes without employing simulation. They provide quick insights into the system under study. These methods do not require a significant amount of data to be collected and processed. Instead, the steady state predictions are based on parameter estimates from a limited set of observations. The concept is restricted though and applies to a limited class of queuing systems that are said to operate in steady state.

An analytical queueing model using Allen and Cunneen formulae to compute the expected freight trains in queue per yard subsystem ($L_{q,Gi}$) is provided to study Entroncamento Double-Ended Flat-Shunted Yard performances. Entroncamento yard is the biggest facility of this type in Portugal and employs pairs of working resources serving freight trains independently of each other. The results obtained for the current situation in Entroncamento indicated significantly low utilisation levels of Entroncamento yard subsystems. Therefore, a new scenario has been proposed. We have examined what changes would be experienced by the yard in question if the pairs of working resources serve the same freight trains simultaneously.

The analytical queueing model showed that Entroncamento yard would experience a reduction of approximately 25 minutes in Throughput time per freight train on average if the new scenario is implemented.

Nota Bene

The reader is advised that the raw data collected and used throughout this work have intentionally not been presented in full operational detail. This is to ensure the security of confidential information provided by the railway freight operator under study “CP Carga”, and also ensures this study does not violate any current strategic actions and agreements in which the railway freight operator under study is involved.

Acknowledgments

The authors wish to acknowledge:

- The planning staff at Department of Planning and Control, CP Carga and the operational staff at Entroncamento yard for providing data and validating the results obtained;
- Mr Rui Santos of Instituto Superior Tecnico, Technical University of Lisbon for giving the time to translate the abstract of this paper into Portuguese Language;
- The editor-in-chief and the anonymous reviewers for generously giving their time to referee the manuscript of this paper and provide valuable comments and recommendations.

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